Continuous-GRASP Algorithm Combined with Local Differential Evolution Search for the Solution of Electromagnetic Design Problems

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Abstract — Recently, inspired by the classical Greedy Randomized Adaptive Search Procedure (GRASP) algorithm, a novel variant of GRASP suitable for continuous problems (C-GRASP) was proposed. C-GRASP is a stochastic search metaheuristic algorithm for finding cost-efficient solutions to continuous global optimization problems subject to box constraints. Like the classical GRASP, C-GRASP is a multi-start procedure where a starting solution for local improvement is constructed in a greedy randomized fashion. In this paper, the C-GRASP approach is combined with the Differential Evolution algorithm in order to enhance its performance. The novel algorithm is applied to Loney's solenoid benchmark problem, showing the suitability for electromagnetic optimization.

I. INTRODUCTION

A typical example of the rough objective function surface typical of many electromagnetic problems is shown by Loney's solenoid benchmark problem [1]. Problems of this kind are ideally suited for stochastic techniques which escape from local minima and are not very sensitive to noise in the objective function.

A well-known metaheuristic for the solution of combinatorial (i.e. discrete) optimization problems is the Greedy Randomized Adaptive Search Procedure (GRASP) algorithm [2]. The first phase of GRASP is the so-called construction phase where a feasible initial solution is built. In the second phase a standard local search is used to explore the neighborhood of the constructed solution in order to improve it. The two phases are reiterated several times either independently or using a certain learning scheme and the best overall local optimum is then selected as the final result.

Recently, Hirsch et al. [3] proposed a modification of GRASP which allows the solution of continuous problems (C-GRASP).

Since the Differential Evolution algorithm (DE) of Storn and Price [4] is an extremely efficient algorithm and has been used successfully in the area of electromagnetics [5]-[6], this paper proposes an improved version of C-GRASP which used DE in the local search (C-GRASP-DE). The effectiveness of C-GRASP-DE is tested on Loney's solenoid benchmark problem and its performance is compared with that of the classical C-GRASP and other well-know stochastic algorithms.

II. FUNDAMENTALS OF THE C-GRASP-DE ALGORITHM

C-GRASP consists in a repeated sequence of so-called "construction" and "local improvement" stages. In the construction phase a sequence of line searches is performed separately along the different parameter-space dimensions and then repeated on subsets thereof (the exact mechanism will be presented in the extended paper). Starting from the point identified with this procedure, a local improvement stage tries to improve the current best solution by sampling the objective function on a predetermined set of points (lying on hypercubes or hyperspheres according to the algorithm). After a new local quasi-optimum is reached the algorithm starts a new initialization step.

In extremely simplified terms the procedure performs a sequence of gradient-less minimizations from multiple starting points.

From the algorithm's description it is clear that the procedure shows major deficiencies in the local improvement stage for two reasons: regular sampling is an extremely inefficient local minimization method and it suffers strongly from the curse of dimensionality (the exponential increase in search space size with the number of degrees of freedom).

In this paper we therefore explore the possibility of improving C-GRASP by modifying the local improvement phase with an algorithm which retains the advantage of the original procedure (i.e. no need for derivative information) while significantly improving its performance.

Among the possible algorithms for local derivative-free optimization we choose DE because it uses a rather greedy and less stochastic approach to problem solving compared to other evolutionary algorithms and is therefore extremely aggressive (at a slightly increased cost of remaining trapped in local minima, which however is not a problem in this context since the search area is a local one and the procedure is repeated from several starting points). DE uses floating-point encoding scheme and combines simple arithmetic operations with the classical events of mutation, crossover and selection to evolve from a randomly generated initial population to a satisfactory one. Due to its extreme efficiency DE is applied to the local improvement cycle in C-GRASP-DE.

Since the desired effect is a very fast convergence the so-called DE*/best/1/bin* strategy is used, in which target individuals are always created from the current optimum.

III. LONEY'S SOLENOID DESIGN

Loney's solenoid design problem consists in determining the position and size of two correcting coils in order to generate a uniform magnetic flux density within a given interval on the axis of a main solenoid. The problem is described by two degrees of freedom (the separation *s* and the length *l* of the correcting coils) with box bounds (see Figure 1).

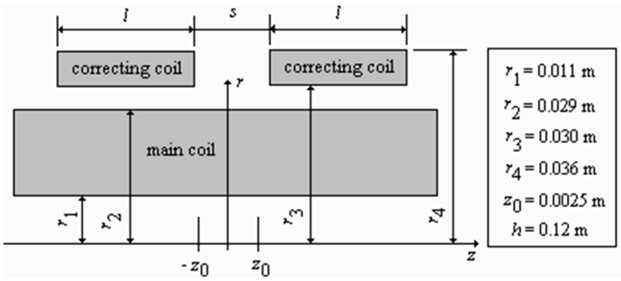

Fig. 1. Axial cross-section of Loney's solenoid (upper half-plane).

Three different basins of attraction of local minima can be recognized in the domain of F with values of $F > 4\cdot10^{-8}$ (high level region: HL), $3\cdot10^{-8} < F < 4\cdot10^{-8}$ (low level region: LL), and $F < 3\cdot10^{-8}$ (very low level region - global minimum region: VL). The very low level region is a small ellipsoidally shaped area within the thin low level valley. In both VL and LL small changes in one of the parameters result in changes in objective function values of several orders of magnitude, as shown in Fig. 2.

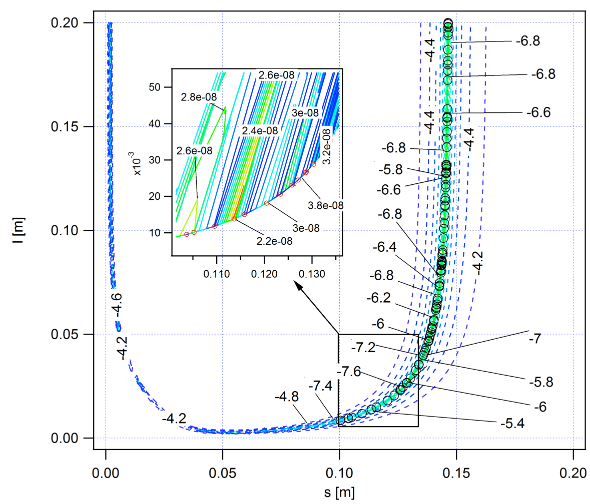

Fig. 2. Objective function landscape and detail of the VL area

For benchmarking purposes the control parameters of classical C-GRASP and C-GRASP-DE were a stopping criterion of 4,000 objective function evaluations in each run. The adopted DE uses a DE/*best/1/bin* strategy with control parameters *MF* and *CR* being random numbers with uniform distribution in range [0.4,0.6] and [0.1,0.9], respectively. Furthermore, population size was set to 15 and the maximum of generations in the local DE search was 20, i.e. each local improvement stage consisted of 300 function evaluations

Tables I and II show the simulation results over 30 runs. In the same tale results obtained with other algorithms [7] are also reported. It can be noted that the proposed improvement allows C-GRASP to become almost as good as some well-known optimizers, especially as far as the best solution is concerned, while improvements in the standard deviation and mean value are still required.

TABLE I
SIMULATION RESULTS OF F IN 30 RUNS

Optimization Method	$F(s, l)\cdot10^{-8}$			
	Maximum (Worst)	Mean	Minimum (Best)	Std. Dev.
C-GRASP	172.0715	76.372	3.1999	36.7114
C-GRASP-DE	33.1231	5.0629	2.0589	5.8679
Cultural SOMA	3.8761	3.2671	2.0595	0.5078
Tribes (PSO)	3.9526	3.4870	2.0574	0.5079

TABLE II
BEST SOLUTIONS FOR LONEY'S SOLENOID IN 30 RUNS

Optimization Method	separation *s* (cm)	length *l* (cm)	$F(s, l)\cdot10^{-8}$
C-GRASP	12.3804	2.1013	3.1999
C-GRASP-DE	11.4989	1.4508	**2.0589**

IV. CONCLUSION

This paper proposes an improvement of C-GRASP with DE in the local search phase. Results on a benchmark featuring many of the characteristics of typical electromagnetic design problems show promising results. In the extended version of the paper the algorithm will be presented in more detail and further test problems will be used. Furthermore, additional improvements will be introduced in order to decrease the spread of solutions and their average value.

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